Instrumentation Amplifier

with an electrically isolated input

By B. Schädler

The instrumentation amplifier described here has two important features. Its input is electrically isolated and it has no fewer than 16 input and output ranges that can be selected for many types of signal conversion.

Most commercial instrumentation amplifiers provide a number of input ranges, but their outputs are usually restricted to one or two voltage ranges and a similar number of current ranges. In this circuit there is a wide choice of input and output ranges: seven unipolar voltage ranges (varying from 0 to 100 mV to 0 to 10 V), seven bipolar voltage ranges (±100 mV to ±10 V) and two current ranges (0 to 20 mA and 4 to 20 mA). The output can be chosen to follow the input on a 1:1 basis, but conversion between any of the ranges is also possible.

Selecting the input and output range is simply done using two DIP switches. The accuracy of all ranges is very good; with careful selection of the resistors a precision of 0.1% is achievable. Two voltage references (IC12 and IC13) are used to maintain accuracy, and presets are used at several critical points.

The electrical isolation is achieved using an optoisolator made by HP (HCNR200 or -201). Its linearity is 0.01%. An alternative part would be the Siemens IL300.

The circuit can be split into three parts:

1) Input stage (with quad opamp IC1) and optoisolator IC3.
2) Amplification and conversion of the optoisolator output into a voltage output.
3) Current output stage.

Input stage

S1A is used to select between a voltage and current driven input. The open position corresponds to the voltage input. The input impedance then is about 1 MΩ, determined by resistors R3 and R1/R2. Capacitor C1 is used to suppress any spikes in the input signal, although a suppression diode could be used instead. Closing S1A changes the input to current mode with an impedance of 50 Ω.

IC1.B functions as a buffer, with IC1.A providing gain/attenuation as required. The gain is changed using switches S1B through S1E. Switch S1F is opened when a current range of 4 to 20 mA is required. For all other ranges the negative voltage reference is connected to the output of IC1.B via R8 and has a negligible effect.

All unipolar inputs are converted to a range of 0 to –1 V at the output of IC1.A; bipolar inputs become +1 V to –1 V. The next stage around IC1.C is used to turn a bipolar ±1-V-signal into a voltage of 0 to +1 V. When S1G is open the –1 V-signal is simply inverted by IC1.A; with the switch closed the gain of IC1.C is halved, while at the same time a reference voltage is added via R16/R17, causing the output to be in the range of 0 to +1 V.

This is followed by the optoisolator (IC3). The internal LED illuminates two photodiodes. One of these is connected back to the input of the output opamp; the other goes to the inverting input of opamp IC1.D. During normal operation the current through R18 and R19 is 'neutralised' by an identical current, but of opposite polarity, delivered by the photodiode. In other words, the opamp drives the LED such that the above condition is satisfied. Assuming that no current flows into the input of the opamp, the photodiode current will be equal to the driving voltage (0 to +1 V) divided by R18+R19. The photodiode current therefore varies from 0 to 50 µA, a value that keeps IC3 operating in its optimum linear range.

Since any current flow into the inverting input of the opamp affects the linearity of the whole circuit, a type has been chosen with a very low input bias current: the OP497 made by Analog Devices. The LT1097 made by Linear Technology is also suitable. If high linearity is not so important it is possible to use a cheaper FET opamp, such as the TL074.

Output stage

The second photodiode in IC3 is connected directly to the inverting input of IC2.A. Since there will be slight differences in the currents sourced by the diodes in the optoisolator, the

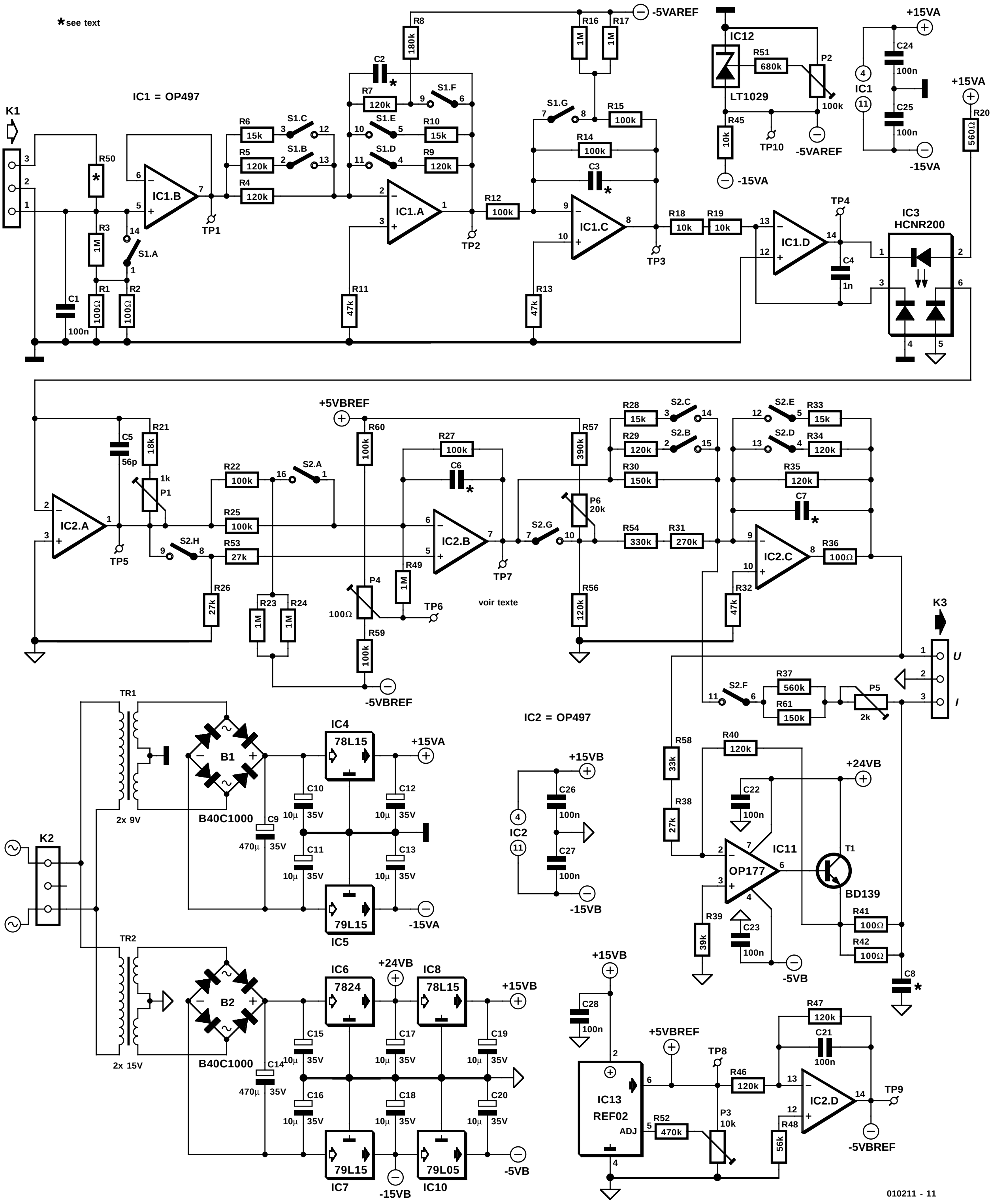

Figure 1. The input of the instrumentation amplifier is electrically isolated from the output by optoisolator IC3.

gain of this opamp has been made adjustable by the addition of P1. When correctly adjusted, the output of IC2.A will be 0 to +1 V.

The next stage with IC2.B is used to give either a unipolar or bipolar output. With S2A open the output is a unipolar 0 to –1 V, with S2A closed the output is a bipolar –1 V to +1 V. At this point any offset errors introduced in the amplifier can be minimised by P4.

The voltage output stage is more or less the same as that at the input; S2B - S2E set the required gain/attenuation. When the voltage output is selected S2G needs to be closed and S2F open. With S2F closed and with the gain of the voltage output stage set at 0.5, IC11 and IC2.C form a voltage to current converter. The gain of IC11 itself is set at a factor of 2.

Table 1. Setting the DIP switches for the various input and output ranges.

Input		**S1-G**	**S1-F**	**S1-E**	**S1-D**	**S1-C**	**S1-B**	**S1-A**
0..+10V		0	1	1	1	0	0	0
0.. +5V		0	1	1	1	0	1	0
0.. +2V		0	1	0	1	0	0	0
0.. +1V		0	1	0	0	0	0	0
0.. +500mV		0	1	0	0	0	1	0
0.. +200mV		0	1	0	1	1	1	0
0.. +100mV		0	1	0	0	1	1	0
-10V.. +10V		1	1	1	1	0	0	0
–5V.. +5V		1	1	1	1	0	1	0
–2V.. +2V		1	1	0	1	0	0	0
–1V.. +1V		1	1	0	0	0	0	0
–500mV.. +500mV		1	1	0	0	0	1	0
–200mV.. +200mV		1	1	0	1	1	1	0
–100mV.. +100mV		1	1	0	0	1	1	0
0.. 20mA		0	1	0	0	0	0	1
4.. 20mA		0	0	0	0	0	0	1
Output	**S2-H**	**S2-G**	**S2-F**	**S2-E**	**S2-D**	**S2-C**	**S2-B**	**S2-A**
0..+10V	0	1	0	0	0	1	1	0
0.. +5V	0	1	0	0	1	1	1	0
0.. +2V	0	1	0	0	0	0	1	0
0.. +1V	0	1	0	0	0	0	0	0
0.. +500mV	0	1	0	0	1	0	0	0
0.. +200mV	0	1	0	1	1	0	1	0
0.. +100mV	0	1	0	1	1	0	0	0
–10V.. +10V	0	1	0	0	0	1	1	1
–5V.. +5V	0	1	0	0	1	1	1	1
–2V.. +2V	0	1	0	0	0	0	1	1
–1V.. +1V	0	1	0	0	0	0	0	1
–500mV.. +500mV	0	1	0	0	1	0	0	1
–200mV.. +200mV	0	1	0	1	1	0	1	1
–100m.. +100mV	0	1	0	1	1	0	0	1
0.. 20mA	1	1	1	0	1	0	0	0
4.. 20mA	1	0	1	0	1	0	0	0
1 = closed								

The reason for the choice of these gains lies with the supply voltage of IC11: in order for the current output to drive a large resistive load (at least 1 kΩ), it needs a high supply voltage of +24 V. There is therefore no choice but to use a reduced negative supply of –5 V, which obviously restricts the negative output swing of the opamp. It is for this reason that the gain of IC2.C is set at a factor of 0.5. Since IC11 is only required to supply a positive output and its output swing is very large, setting the gain of IC11 to 2 causes the overall gain of the current source to be unity.

When calibrated correctly, the maximum output current depends only on the driving voltage (0 to +1 V) of the current source and parallel resistors R41/R42 (50 Ω). Another condition is that the feedback resistor has to be exactly 120 kΩ – 50 Ω; which can be adjusted precisely with P5.

To turn the current mode of the amplifier to 4 to 20 mA, switch S2G is opened, causing a small voltage to be added to the input of the current source. Since the maximum output current should remain at 20 mA, the gain is adjusted slightly at the same time.

Since the current source requires a positive input voltage, inverting opamp IC2.B is effectively bypassed by closing switch S2H. Preset P6 is used to set the range exactly to 4 to 20 mA.

And finally, capacitors C1 -C7 should be mentioned. These capacitors are used to limit the bandwidth of the circuit. With a value of 1 nF the bandwidth is about 100 Hz and with 100 pF it is about 10 kHz, with an input signal of ±10 V. Choosing too small a value for C4 and C5 can give rise to unwanted oscillations, with C4 being very critical.

Power supply

As shown in the circuit diagram, the power supplies for the input and output stages are completely isolated. The supply for the input stage is kept fairly simple since only a symmetrical ±15 V is required. This is provided by a standard circuit using two voltage regulators (IC4 and IC5). The supply for the output stage consists of four voltages: ±15 V for IC2 and +24 V/–5 V for IC11. As can be seen, the rectified voltage of TR2 is first fed to IC6 and IC7, providing +24 V and –15 V. These supplies are then fed to IC8 and IC9 to give +15 V and –5 V.

The power consumption of the complete circuit is very low, making it possible to use small 1.5 VA PCB mounted transformers for TR1 and TR2.

Calibration

As far as the construction of this circuit is concerned, it is very much a DIY project. The author did design a PCB for his own use, but it had undergone so many modifications during the development of the circuit that the layout was no longer suitable for reproduction. Aspiring hobbyists will therefore have to design their own PCB for this circuit.

The calibration of the circuit is a meticulous task, which should be followed carefully. Fortunately, it isn't very difficult.

1) Switch on the amplifier and all calibration instruments (power supply, multimeter) and let them settle for about fifteen minutes.
2) Adjust P2 and P3 to set the voltage references to their nominal value (test points TP8, TP9 and TP10). Remember that there are two ground points!
   - Adjust P4 for an offset of 0 V at its wiper (TP6).
3) Use Table 1 to set the DIP switches for an input of 0 to +1 V and connect a voltage of 1.000 V to the input. Check that TP1 is +1.0 V, TP2 is –1.0 V and TP3 is +1.0 V.
4) Connect the multimeter to the other ground and set S2 to an output range of 0 to +1 V.
5) Adjust P1 to get +1.0 V at the output of IC2.A (TP5).
6) Short the input to ground. Use P1 and P4 to adjust the output to its exact value. Do the same again with an input of 1.000 V. The voltages at TP7 should now be 0 to 1 V for the unipolar range and +1 V to –1 V for the bipolar range.
7) With an input range of 0 to +1 V switch over to a current output and connect an ammeter between pin 3 of K3 and ground. Adjust P5 with a minimum and maximum load (1 kΩ) to give a 20 mA output current. Use P4 to set the 0 mA point.
8) Switch over to the 4 to 20 mA range and adjust P6 to give exactly 4 mA. If necessary, P1 and P4 can be adjusted to provide the best accuracy.
9) With bipolar inputs and outputs use P4 to adjust the offset to 0 V (input at 0 V). Next, adjust the gain (P1) with a positive input, then connect a negative input, but don't check the output. Again (with the input at 0 V) adjust the offset and with a positive input, the gain. Step 9 should be repeated until the best accuracy has been achieved.

Finally

The ground reference point for input signals and the multimeter should always be that at the input connector. The measurement of the input voltage should also be taken at the input connector. It is recommended to check that none of the opamps is oscillating. Especially IC1.D and IC2.A can be sensitive to this; increasing C4 and C5 in value should help.

If required, R41/R42 can be changed to select different output current ranges. Do take care that the supply transformer is rated for that current.

By choosing different values for resistors R1, R2/R3, as well as R50, virtually any input voltage can be measured.

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Despite the fact that the lack of a PCB prevented us from testing this circuit thoroughly in the Elektor labs, we felt that this design was worthy of publication. We can't comment directly from our own experiences on the usefulness of this circuit. Theoretically, the circuit seems to be in order and it is clear that the author has put a great deal of thought into the design. (Ed.)